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Technical Report

REMOTE SENSING TECHNIQUES FOR MAPPING RANGE SITES AND ESTIMATING RANGE YIELD

by

L.A. Benson, C.J. Frazee, F.A. Waltz,
C. Reed, R.L. Carey, and J.L. Gropper

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ABSTRACT

Image interpretation procedures for determining range yield and for extrapolating range information from test sites to surrounding similar resource areas were investigated for an area of the Pine Ridge Indian Reservation in southwestern South Dakota. Herbage yield estimates and soil capability ratings are needed to establish stocking rates for grazing permits on Indian land. Soil and vegetative data collected in the field utilizing a grid sampling design and digitized film data from color infrared film and black and white films were analyzed statistically using correlation and regression techniques. The pattern recognition techniques used were K-class, mode seeking and thresholding.

Herbage yield (lbs. of dry matter per acre) was significantly correlated with digital data from both color infrared film (Kodak 2443 with 15G/30M filters) and black and white film (Kodak 2402 with 58 or 25A filter), but not with black and white infrared film (Kodak 2424 with 89B filter). None of the correlated film variables were significantly different for predicting yield. Also the correlation between herbage yield and the digital film data did not significantly improve by using transformations of the film data or film data from more than one band. The herbage yield equation derived for the detailed test site was used to predict yield for an adjacent similar field. The herbage yield estimate for the adjacent field was 1744 lbs. of dry matter per acre which compares

favorably with the mean yield of 1830 lbs. of dry matter per acre based upon the ground observations. Extrapolation of uncorrected film data using regression or pattern recognition methods was limited due to sun angle and vignetting effects.

An inverse relationship between vegetative cover and the ratio of MSS 5 to MSS 7 of ERTS-1 imagery was observed. Within a general resource area this index is a measure of land cover, either cropland or rangeland. Future research on predicting range yield from remote sensing imagery should be conducted using the ratio of MSS 5 to MSS 7 of ERTS-1 imagery as a stratification of the rangeland. Subsampling of the areas delineated by the ratio will be necessary to provide yield estimates.

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REMOTE SENSING TECHNIQUES FOR MAPPING RANGE SITES AND ESTIMATING RANGE YIELD

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INTRODUCTION

The Bureau of Indian Affairs is responsible for the proper utilization of 67,000,000 acres of Indian land. The increased emphasis today on environment and ecology requires the resource manager to have the best and most current data available for planning and decision making.

Soil and range inventories, where complete and up-to-date, currently provide the basic resource information for land use and management decisions on Indian lands. These inventories provide detailed information on soils, range sites, land use, watering points, erosion hazards, and several other categories of information obtained during a field survey. Coupled with information on climate, rainfall, and geology, the data in these surveys permit

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[2]Soil Specialist, Remote Sensing Institute; Assistant Professor, Plant Science Department; Data Handling Specialist, Remote Sensing Institute, South Dakota State University; Range Scientist, Rosebud Agency; Area Soil Scientist, Bureau of Indian Affairs; and Research Assistant, Remote Sensing Institute, South Dakota State University, Brookings, South Dakota 57006

estimates of stocking rates, crop yields, feasibility of irrigation, and suitability for a variety of land use alternatives. Unfortunately, the field work necessary to conduct these surveys is very time consuming and expensive.

Previous work at the Remote Sensing Institute in cooperation with the Bureau of Indian Affairs has demonstrated that much of the soil and range information obtained by field surveys can be interpreted from photographs (Frazee and Carey, 1972; Frazee, Carey, and Westin, 1972; and Frazee, Gropper, and Westin, 1973). A land classification system has been developed for use with ERTS imagery and photography that delineates and subdivides major land units (regions and systems) based on photo characteristics as related to physiography. At the lowest level in the system (facets), the units correlate closely with current soil and range site categories (Frazee et al., 1973). This system is recommended as a rapid source of information where soil and range inventories are not available (Benson, Frazee, and Myers, 1973).

In South Dakota, where soil and range inventories of Indian land are available, a need exists for new techniques to monitor land use changes and to periodically update and improve existing inventories. Previous work at the Remote Sensing Institute has demonstrated the potential of density slicing techniques for improving soil and range site maps (Frazee, Myers, and Westin, 1972).

ERTS-1 imagery was evaluated for its usefulness in updating soil and range inventories (Frazee, Carey, and Gropper, 1973).

The problem studied in this report was that of estimating range production (herbage yield) using remote-sensing technology.

The objectives for this study were:

1. To establish procedures for determining range yield for test sites of characteristic range areas in Bennett County, South Dakota.
2. To establish techniques for extrapolating range and soil information from test sites to other similar areas.

DESCRIPTION OF THE STUDY AREA

The study area consisted of a strip 4 miles wide crossing Bennett County, South Dakota from north to south (Figure 1). Bennett County is part of the Pine Ridge Indian Reservation, and a large portion of the land (300,000 A) is still in Indian ownership. Considerable information is available on the soils and range from the Bureau of Indian Affairs (BIA, 1963) and the Soil Conservation Service (Radeke, 1971). The flight line transects three major physiographic regions: the Sandhills Region from Nebraska into the southern part of the county; the silty, undulating tableland region (Martin Tableland) in the central part; and a loamy, rolling plain (Arickaree Plain) in the northern half.

Approximately 75 percent of the county is rangeland and is covered by native mid to short range grasses. The principal range sites in the Sandhills Region are: sands, choppy sands, and subirrigated. In the rest of the study area they are: silty, overflow, thin upland, and shallow. Cropland accounts for approximately 23 percent of the county. Most of this is devoted to a dryland fallow and winter wheat rotation, although other grains and forage crops are grown. The climate is semiarid and continental with large variations in seasonal temperature and precipitation.

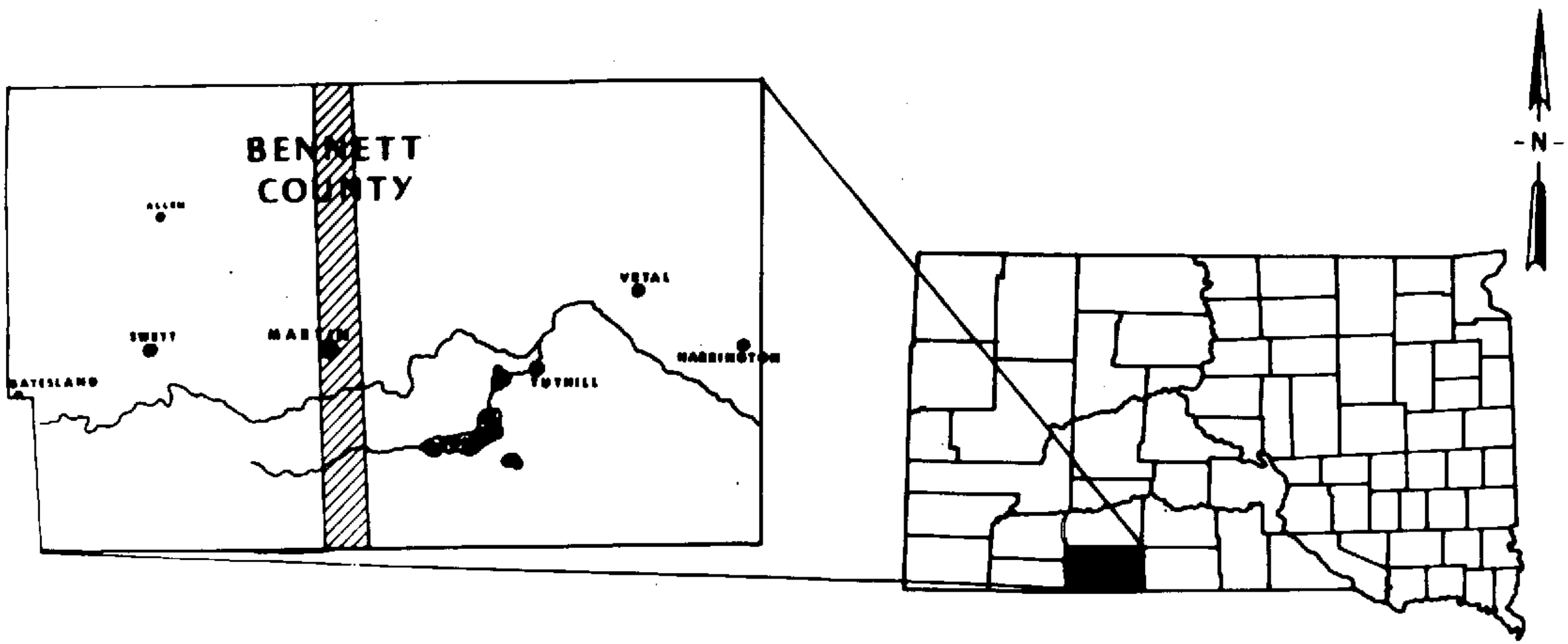


Figure 1. - Location of flight line in Bennett County, South Dakota.

MATERIALS AND METHODS

DATA COLLECTION

Data were collected through a cooperative effort by RSI and BIA personnel during 1971 and 1972. In addition, an effort was made in August 1973 to obtain albedo measurements with the four channel Exotech radiometer for several range sites and plant canopies using ERTS-1 MSS bands. The collection of field and film data is described separately in the following paragraphs. The field data consisted of measurements made in the field and in the laboratory on range and soil information collected from eight test sites selected as characteristic of the soils of the study area. Aerial data were collected over the entire study area, but were only digitized and analyzed in detail for the test sites.

The field data consisted of measurements and descriptions of range and soil properties and characteristics taken at 100-meter intervals resulting in 49 observations for a typical quarter section (160 acres). Three parties were utilized in the field work, which was conducted during July 1972. The first party laid out the 100-meter grid and photographed each site, a second party clipped and described the vegetation, and a third party sampled and described the soil.

Soil data obtained during the field work included:

1. profile description of each of the horizons
2. sample of the surface
3. soil series designation

Subsequent laboratory analyses of the surface soil samples provided

the following data:

1. Munsell color (dry)
2. Soil reflectivity measured at 0.6μm
3. Organic matter content

A probe truck was utilized to obtain core samples of soil profiles. Soil reflectivity was measured under artificial light that peaked at 0.6μm using an Isco spectroradiometer with a remote probe attachment. Organic matter was determined by the South Dakota State University Soil Testing Laboratory using standard procedures.

Range data obtained during the field work included:

1. clipping sample for yield
2. sample of plant litter
3. range site designation
4. estimates of yield, condition, % useable and species composition

The air dry weights of the mulch and clipping sample were multiplied times a constant (air dry wt. in grams x 50 = lbs/A) to obtain:

1. Herbage yield (live) in lbs/A
2. Herbage yield (mulch) in lbs/A
3. Herbage yield (live and mulch) in lbs/A
4. Herbage yield (live and %useable) in lbs/A

The clipping sample was obtained by clipping all vegetation within a 1.92 square foot area with a battery operated shears. The mulch sample was collected with the aid of a small rake. Two replicate samples were randomly selected within a 10 foot x 10 foot square. The sample squares were all placed in the same orientation to the grid points on the ground.

Each sample was placed in a bag, labeled, and taken to the Remote Sensing Institute for drying and weighing.

The film data used in the project were collected by the Remote Sensing Institute aircraft in 1970, 1971, and 1972, under NASA contract NGL 42-003-007. The flight line crossed Bennett County from north to south and centered on Martin, the trade center for the county (Figure 1). Photo and thermal scanner missions were flown on the following data:

Date	Sensors	Altitude Above Ground Level
October 15, 1970	4 70-mm cameras and scanner	12,000
June 30, 1971	4 70-mm cameras and scanner	12,000
August 2, 1971	4 70-mm cameras and scanner	11,500
June 12, 1972	4 70-mm cameras and scanner	10,000
July 23, 1972	4 70-mm cameras and scanner	10,000
July 29, 1972	K-17 (12") camera and scanner	10,000

All missions were conducted within 2 hours of solar noon to minimize sun-angle problems. Each of the four 70-mm Hasselblad cameras contained a different film/filter combination as shown below:

Camera	Film	Filter	Abbreviation
1	B/W Plus-X (2402)	25A	B/W-25A
2	B/W Plux-X (2402)	58	B/W-58
3	Color Infrared (2443)	G15 & 30M	EK-IR
4	B/W Infrared (2424)	89B	B/W-89B

The film from the July 23, 1972, mission was selected for analysis since it was obtained at the same time as the field data. Unfortunately, a gap existed in the coverage of this mission, and the June 30, 1971, imagery was used for the sites where the gap occurred. Imagery from

several of the missions were also plagued by the presence of cumulus clouds over part of the flight line.

The selected films from all four cameras were placed over a light table and test sites were masked with black tape. The film was then digitized by the Signal Analysis and Dissemination Equipment (SADE), Figure 2. The masked sites were placed over the light source and the image dissector measured the transmittance of the film and recorded it as output codes on computer tape. The procedure was repeated for each of the three black and white films (B/W-58, B/W-25A, and B/W-89B). The color infrared (EK-IR) film was digitized without a filter (N), and repeated with a green filter (G), a red filter (R), and a blue filter (B) to extract data from the individual emulsion layers. Due to the false color nature of color infrared film, the blue filter corresponds to the green sensitive layer, the green to the red, and the red to the infrared. The above designations will be used throughout this paper to designate the various types of digital data. The resulting digital output codes were used for subsequent correlation with the field data.

Density slicing was also conducted using the Spatial Data system (Figure 3) as both an interpretive tool and as a method of extrapolating from a study area. This approach was limited to single feature (film) analysis, but did provide an enhancement of photographic tone to a maximum of 32 levels. The automatic planimeter feature of this device allowed rapid area measurement of any of the 32 levels (colors). When used as an interpretive tool, the gain was adjusted until the test area was encoded into one or more colors.

SADE was designed as a state of the art data analysis system with a highly flexible modular design. In the independent off-line mode the system provides monitor display of digital film or analog tape data and transmission of analog information to the film printer. When on-line with the computer, the system provides transmission of digitized image data and analog tape data to the computer and transmission of data stored or transformed in the computer back to the display monitor or the film printer. The system is composed of the following components:

1. Image digitizer (image dissector tube)
2. Data control and conversion unit
3. Lockheed 417 seven track analog tape recorder
4. Daedalus film printer
5. Band pass filters
   Red - .59 - .70μm
   Green - .47 - .62μm
   Blue - .36 - .50μm

Figure 2. Signal Analysis and Dissemination Equipment

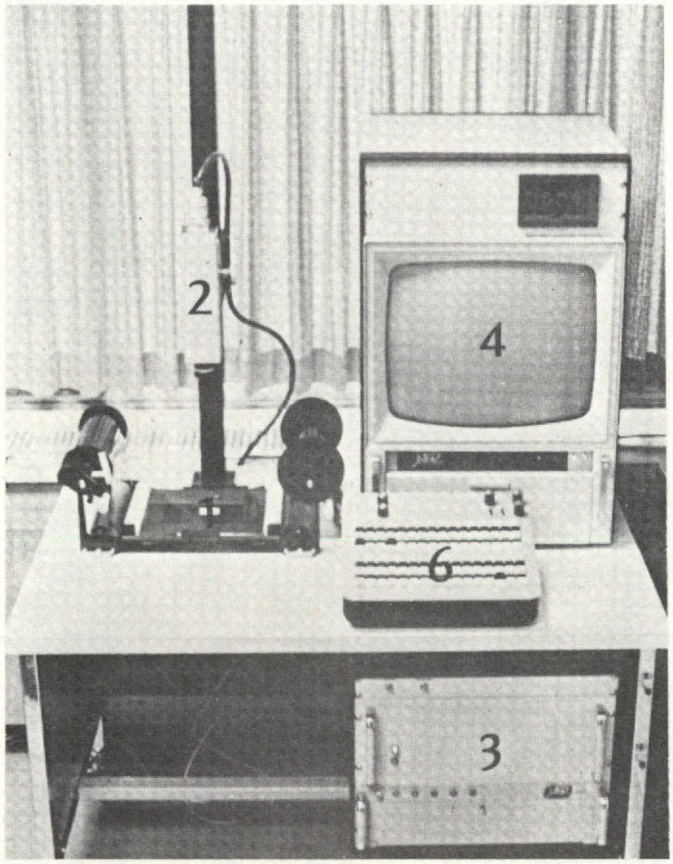
To extrapolate this information, the gain and all controls were fixed and the entire frame or adjoining frames were measured.

DATA ANALYSIS

The data were subjected to three basic types of analyses: a statistical analysis consisting of correlation and regression; pattern recognition; and interpretation and enhancement. The last named was used to extrapolate from the test site to larger areas. The goal of the statistical analysis was to determine the relationship between the film data and the field data. The other two methods of analysis provided an empirical solution to estimating range yield or mapping range site.

The statistical analysis began by correlating separately the field data variables and the film variables. This permitted an evaluation of each type of data prior to correlating the film data with the field data. Next, the film variables were correlated with the field variables. The computer program used for this purpose provided means, standard deviations, correlation coefficients, regression coefficients, and regression intercepts. The preceding analysis was also conducted using transformations of the film data to correlate with the field data. Transformations such as B/W-25A divided by B/W-89B and B/W-25A minus B/W-89B were used.

The pattern recognition techniques attempted included K-class (Serreyn and Nelson, 1973) and mode seeking programs. The supervised K-class technique required the selection of training samples (areas)



The Spatial Data system is an instrument for analyzing density patterns. The transparency is viewed by a black and white television camera, and the electronic signal from the camera is separated with respect to the various density levels of the transparency. The density levels are encoded into colors selected by the operator and displayed on the color television monitor. Up to 32 desnsity levels or colors may be used at one time. The system has the following components:

1. Light box to illuminate the film
2. Precision monochromatic TV camera
3. Electronic color analyzer
4. Color television monitor
5. Electronic planimeter
6. Control keyboard

Figure 3. Spatial Data Datacolor Model 703

within the test site for each desired class and training the computer to recognize these samples or classes using data from one or more films. Once trained, the machine classified the entire site based on the training samples. The mode seeking technique is an unsupervised approach in that the program determines the number of modes in the data and allows the investigator to combine the modes as he desires. A thresholding classification technique was attempted using results from linear regression and visual inspection of digital data.

The interpretation and enhancement techniques included manual photo interpretation, photo enhancement with density slicing, and interpretation of digitized film and ERTS-1 imagery. The above methods were attempts to extend or extrapolate the results from the test sites to other areas. Maps prepared from field observations were visually matched to maps prepared by density slicing. Density slicing maps were compared to the field data collected at the grid points. Adjoining fields with the same soil and range characteristics were classified using the same settings on the density slicing device as the test site. A frame and both overlapping frames were digitized to study the effects of sun angle and vignetting in the hope that an empirical correction could be developed. A section of ERTS-1 imagery covering the study area was digitized to determine if ERTS-1 imagery could be used to extrapolate from test sites to large areas. The MSS 5 and MSS 7 transparencies for the August 18, 1972, overpass were digitized, subtracted, and ratioed in the search for a vegetative index or estimate of herbage yield.

RESULTS AND DISCUSSION

Initially the relationship of range condition and utilization to photographic tone did not provide meaningful results, primarily because the areas studied were similar in range condition and utilization. A 60-acre test site characteristic of the northern half of the study area (Pasture 1) was selected for initial study. An adjoining 160-acre test site of similar composition (Pasture 2) was used for extrapolation of the results obtained from Pasture 1.

During the collection of clipping subsamples, a very large variation of herbage yield between subsamples was noted. This large variation, which was significantly different for the subsamples within a 10 foot x 10 foot square, reduced the reliability and confounded subsequent analyses. So that the analysis might continue, the two subsamples were averaged to provide one estimate of yield for each 10 foot x 10 foot square.

STATISTICAL ANALYSIS

During the course of the statistical analysis, the mean output codes from several matrix sizes around the plotted point were correlated with field data to determine the optimum matrix size. Sample sizes from 1 x 1 to 7 x 7 corresponding to ground plots from 3 x 3 meters to 21 x 21 meters, respectively, were correlated. The results showed very little difference due to matrix size, and a 5 x 5 matrix (25 output codes) was used since it approximated the accuracy in plotting the ground points on the computer printout of the digital film data. A computer program was written during the course of the analysis that

allowed the selection of any desired matrix size around any given coordinates. The numbers in the matrix were subsequently averaged and a mean for the coordinates were provided. For example, this program allowed the researcher to read 49 coordinates and receive mean output codes for these coordinates for all seven matrix sizes from seven different film/filter combinations. The results were interpreted in terms of the field data, the film data, and the field and film data together. The correlation was repeated using seven different matrix sizes for the film data. The optimum matrix size was assumed to be the one that provided the highest correlation coefficient.

The results from statistical analysis of the field data provided an estimate of the reliability of the field data and the variation within it. The results for Pasture 1 are presented in Tables 1 and 2. The means and standard deviation presented in Table 1 provide an estimate of composition and variability for the pasture. Correlation coefficients for 11 of the 29 field variables are presented in Table 2. Variables pertaining to species composition and some redundant variables were omitted.

Linear correlation of the field data provided some interesting results. The correlation of the two clippings within the 10 foot x 10 foot plot was lower than expected (r=.64). A closer look at the variation between these subsamples indicated a variation of $\pm$ 1600 lbs/A in some instances. The means of sample A and sample B were nearly the same, indicating that the variation between the two samples was random and not due to the method of sampling. This large variation points out the extremely complex nature of the vegetative canopy of a vast

TABLE 1. MEANS AND STANDARD DEVIATIONS FOR DATA FROM PASTURE #1.

VARIABLES	MEAN	STANDARD DEVIATION
Depth of A Horizon (cm)	12	4
Depth of C Horizon (cm)	28	13
Depth of CO_3^{--} (cm)	31.2	15.3
Forage Sample A (g)	31.3	17.1
Forage Sample B (g)	32.6	15.6
Mulch (g)	68.6	60.9
Reflectivity (%)	6.8	.9
Slope (%)	6.7	5.5
Organic Matter (%)	2.4	.3
Munsell Value	4.2	.7
Munsell Chroma	2.0	.1
Condition (% climax)	61	17
Yield (lbs/A)	1632	711
C.S. Total (%)*	64	18
W.S. Total (%)**	27	18
EK-IR N (output codes)	134	22
EK-IR R " "	51	5
EK-IR G " "	65	9
EK-IR B " "	45	3
B/W 58 " "	97	14
B/W 25A " "	84	14
B/W 89B " "	91	13

* Cool season grasses
** Warm season grasses

TABLE 2. LINEAR CORRELATION COEFFICIENTS FOR FIELD DATA FROM PASTURE #1

	Soil Series	Depth of A Horizon	Depth of CO_3^{--}	Slope	Organic Matter	Reflectivity	Value	Range Site	Condition	Yield
Depth of A Horizon	-.82**									
Depth of CO_3^{--}	-.74**	.69**								
Slope	.62**	-.46**	-.32*							
Organic Matter	-.21	.21	.17	-.02						
Reflectivity	.48**	-.60**	-.60**	.33*	.37**					
Value	.47**	-.46**	-.52**	.49**	.17	.68**				
Range Site	.77**	-.57**	-.58**	.72**	.29*	.51**	.48**			
Condition	-.12	.23	.21	.21	.14	-.12	-.02	.00		
Yield	-.47**	.51**	.52**	-.23	.13	-.39**	-.30*	-.41**	.61**	
Mulch	-.26	.28*	.29*	-.19	.00	-.24	-.14	-.19	.21	.60**

* Significant at .05 level (>.279)
** Significant at .01 level (>.362)

majority of the western range area. In one respect, low correlations between the field data were desirable, since this indicated the variables were not interrelated. The high correlation between the reflectivity of the surface soil and such variables as depth of the A horizon, depth of CO_3, and Munsell value of the surface soil were expected and indicated the validity of the data. Forage yield correlated highly with range condition, depth of the A horizon, range site, soil series, and depth of CO_3, but surprisingly low with slope and organic matter content. The high correlation between soil series and range site with the measured field variables indicates the variables selected for field study are representative of present soil series and range site classification systems used by resource scientists. The low correlation between soil series and organic matter was unexpected and not understood.

The results of the correlation of the seven film variables indicated the degree to which the black and white films were related to the color infrared variables and the amount of redundancy between them. The high correlation coefficients shown in Table 3 indicate a large amount of redundancy between the individual color infrared film variables. The black and white film with a green filter (58) correlates highly with the unfiltered color infrared film. The high correlation between the B/W-58 and the B/W-25 indicates the redundancy in these two visible bands. The black and white infrared film (B/W-89B) does not correlate with any of the other films and indicates that it is measuring in a different band of the spectrum than the other variables.

After evaluating the field and film data separately, they were analyzed together with the intent of developing a predictive equation for forage yield. Linear correlation of the field data and the film data showed a significant correlation between several of the variables. The results for Pasture 1 are shown in Table 4. From the table, it is apparent that the color infrared film with the green filter (EK-IR(G)) provided the best correlation with the field data and the black and white infrared film (B/W-89B) the poorest. Yield was significantly correlated with all film variables except the black and white infrared film (B/W-89B) and the highest correlation was with the black and white film with the red filter (B/W-25A).

Linear regression of the data provided a regression equation for predicting the field variables from the film variables. Examples of the regression results are shown in Figure 4. The examples shown are for the output codes from color infrared film digitized without a filter (EK/IR-N), although all seven films were analyzed in this fashion. Several transformations of the film data were correlated with forage yield in an unsuccessful attempt to find a better indicator of forage yield. The transformations of digital data attempted were: ratios of various bands of the color infrared film, N/R, N/G, N/B, G/R, R/B, G/B, and R/G; ratio of black and white film with 25A filter to black and white infrared; subtraction of the black and white film with 25A filter from black and white infrared film; and infrared band of color infrared film from red band of color infrared film (Table 5).

TABLE 3. LINEAR CORRELATION COEFFICIENTS FOR FILM DATA FROM PASTURE #1.

	EK-IR				B/W	
	N	R	G	B	58	25A
EK-IR R	.79**					
EK-IR G	.89**	.76**				
EK-IR B	.62**	.68**	.77**			
B/W 58	-.68**	-.42**	-.54**	-.42**		
B/W 25A	-.59**	-.28*	-.52**	-.38**	.73**	
B/W 89B	-.14	-.13	-.11	-.002	.41**	.19

* Significant at .05 level (>.279)

** Significant at .01 level (>.362)

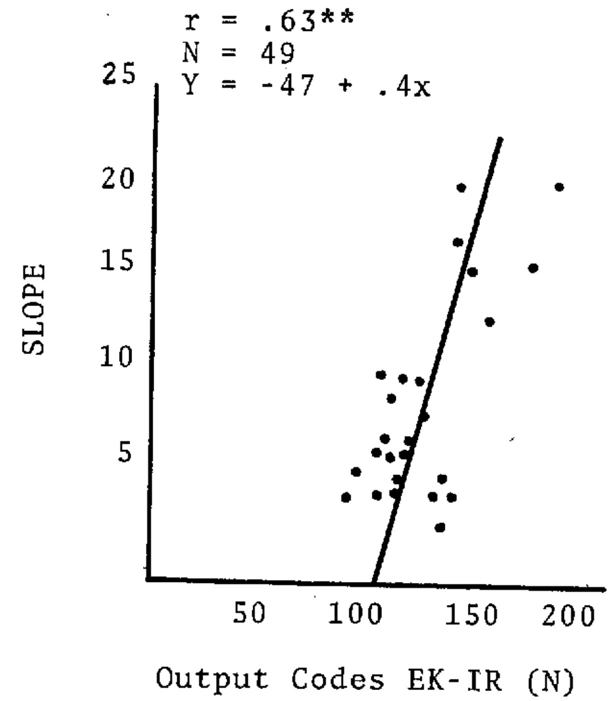
TABLE 4. CORRELATION COEFFICIENTS FROM ANALYSIS OF FIELD AND FILM DATA FOR PASTURE #1

	EK-IR				B/W		
	N	R	G	B	58	25A	89B
Depth of A Horizon	-.36**	-.22	-.42**	-.41**	.46**	.23	.16
Slope	.63**	.53**	.67**	.60**	-.44**	-.24	-.07
Organic Matter	-.09	.01	-.10	-.20	-.01	.04	-.18
Reflectivity	.32*	.26	.30*	.40**	-.28*	-.19	.13
Condition	-.27	-.22	-.19	-.15	.30*	.38**	.28
Yield	-.52**	-.37**	-.48**	-.36*	.52**	.53**	.18

* Significant at .05 level (>.279)

** Significant at .01 level (>.362)

Multiple correlation/regression was performed to determine whether the addition of more independent variables (film variables) would improve the correlation. The analysis was run separately for the color infrared (N,R,G,B) and the black and white film variables. Table 6 indicates that the correlation coefficients were not greatly improved by the addition of more than one film variable.



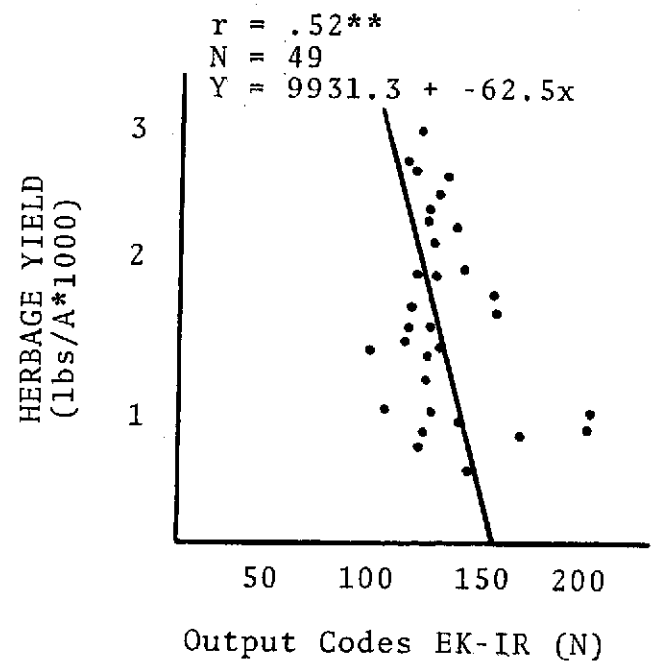


Figure 4. Regression results for selected field variables for Pasture 1.

TABLE 5. Correlation coefficients of transformations used to estimate yield.

TRANSFORMATION	r
EK-IR Film	
N/G	-.23
N/R	-.46**
N/B	-.46**
G/R	-.35*
R/B	-.18
G/B	-.43**
G-R	-.42**
R/G	.34*
B/W Films	
89B - 25A	-.18
25A/89B	.27
G-R	.29*

* Significant at .05 level (>.279)

** Significant at .01 level (>.362)

TABLE 6. MULTIPLE CORRELATION COEFFICIENTS FOR PASTURE #1 FOR HERBAGE YIELD

EK-IR Film

N	N+R	N+R+B	N+R+B+G
.52**	.52**	.53**	.53**

B/W Films

25A	25A + 58	25A+58+89B
.53**	.57**	.57**

** Significant at .01 level (>.36)

COMPUTER CLASSIFICATION

YIELD

The K-class automatic pattern recognition program (Serreyn and Nelson, 1973) was used to classify training samples selected on the basis of the linear regression analysis to determine which bands or combination of bands were best for identifying yield classes. Initially four classes were defined, 0-900, 900-1200, 1200-1800, and 1800-3600 lbs. of dry matter per acre. The output codes from the four sites best representing the yield classes were used as training samples. Regardless of the features used to define the classes, classification accuracy was less than 50 percent.

Due to these poor results, two yield classes were formulated from the original four, 0-1200, and 1200-3600 lbs. of dry matter per acre. Percent correct recognition of these two classes is shown in Table 7. One feature (film-filter combination) was adequate for distinguishing the two yield classes.

RANGE SITE

Three separate computer classification techniques were utilized in the analysis of the digital data. K-class and mode seeking are essentially automatic pattern recognition techniques in that the algorithm in the computer program made the decisions while in the third approach the decision boundary was determined by visual inspection of the digital data and the computer was utilized to make the map. The three techniques are described separately in the following paragraphs:

Table 7. Pattern recognition results for training samples for two yield classes*

Feature	Percent correct recognition	Feature	Percent correct recognition
EK-IR-N	83.7	B/W-G	75.5
R	71.4	R	71.4
G	83.7	IR	69.4
B	73.5	GR	79.6
NR	81.6	GIR	79.6
RG	81.6	RIR	71.4
GB	83.7	G,R,IR	75.5
NG	83.7		
NB	83.7		
RB	77.6		
NRG	83.7		
NRB	83.7		
NGB	83.7		
RGB	81.6		
NRGB	83.7		

* The training set for each class was 450 points.

The K-class technique was used to make a range site map using the means of the 5 x 5 matrix around the ground points, using all 25 digital values for each ground point, and using 25 points as the training sample for each class. The four range sites for each class considered were overflow, silty, thin upland, and shallow. The classifier was trained to recognize these classes with the digitized film data from the seven film/filter combinations. The seven-feature problem was repeated for three classes and two classes. The results were printed out and displayed on the color television monitor (Figure 5). The two-class maps (which showed overflow and silty as one category and shallow and thin upland as the others) were considered more reliable (Table 8) than the three- or four-class maps. The classification of the shallow and thin upland range sites into one category was expected because these range sites have a similar productivity and the criterion for separating the range sites is depth to bedrock, which is not expressed at the soil surface. Examination of the imagery shows a larger contrast within the overflow range site than between overflow and silty range sites. Unfortunately, none of the observations on the grid sampling were in the portion of the overflow range site with high infrared reflectance (Figure 6). K-class was attempted a second time using a different training sample. The maps produced using boundaries determined by the K-class technique are shown in Figure 5. For selecting training samples, any of the above procedures worked equally well.

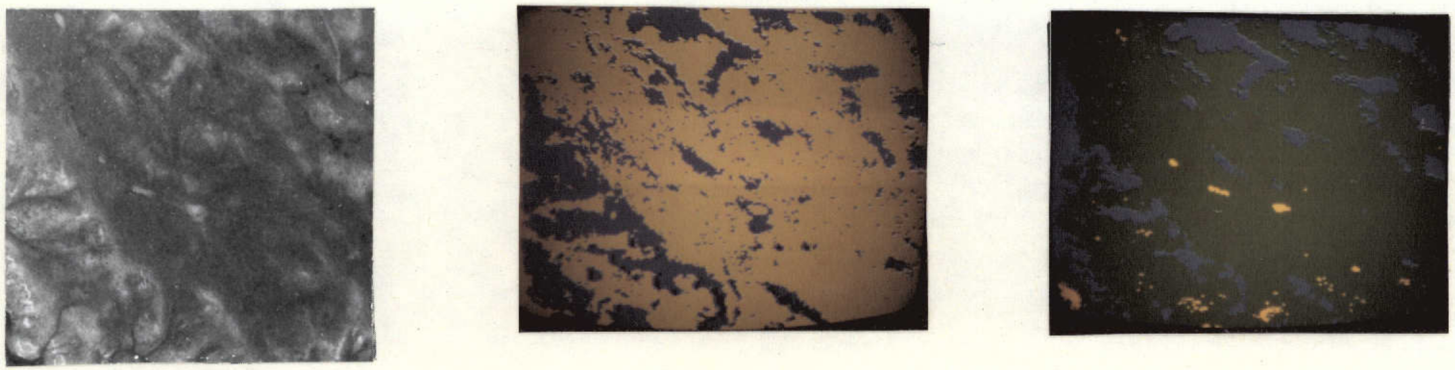
Mode seeking was the second pattern recognition technique attempted. An evaluation of the results indicated the mode seeking

Table 8. Pattern recognition results for training samples for two range site classes

Feature	Percent correct recognition	Feature	Percent correct recognition
EK-IR N	85.7	B/W G	79.6
R	81.6	R	81.6
G	91.8	IR	75.5
B	87.8	GR	81.6
NR	87.8	GIR	83.4
RG	91.8	RIR	81.6
GB	93.9	GRIR	81.6
NG	91.8		
NB	91.8		
RB	91.8		
NRG	91.8		
NRB	91.8		
NGB	93.9		
RGB	93.9		
NRGB	93.9		

algorithm was not applicable due to the large variation in the film data. The possibility of using this technique for preprocessing was not ruled out, but as a technique for automatic recognition of range sites, it was a failure because the modes had to be assigned to the desired classes.

The third computer classification technique utilized the high speed output capability of the computer. Decision boundaries (thresholds) were determined based on an evaluation of the digital printout. The output codes from the film with the highest correlation coefficients were used for this simple feature analysis. Areas representative of the range sites, overflow, silty, and thin upland, were selected. The output codes were studied and grouped into three classes. Figure 5 illustrates the classification results using this technique. This thresholding approach is the most efficient using one feature.



Plus-X film
with 25A filter
July, 1972

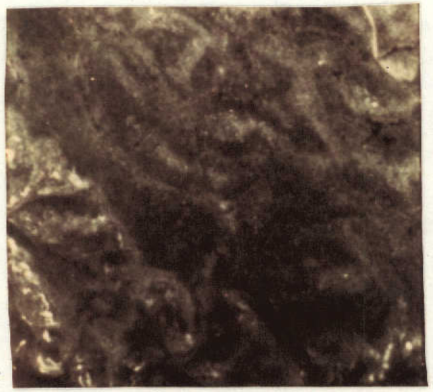
K-class

yellow-silty and
overflow
blue-shallow and
thin upland

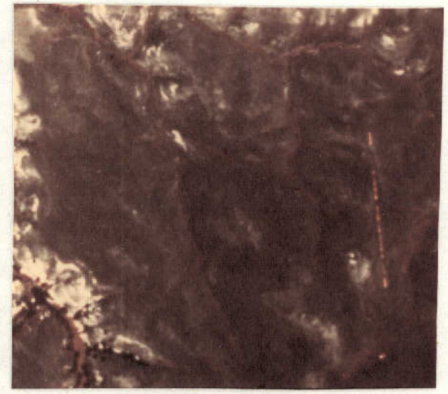
Interactive

yellow-overflow
green-silty
blue-shallow and
thin upland

Figure 5. Classification of range site for Pasture 1.



Pasture 1



Pasture 2

Density Slicing
Analysis

Density Slicing
Analysis

Figure 6. Extrapolation of range site classification to a test area. EK-IR film without a filter July 1972.

EXTRAPOLATION

Using the regression equation derived from Pasture 1, the mean yield of Pasture 2 was calculated. The equation for yield from Pasture 1 using the best film was yield = 9931.3 - 62.5 (output code of EK-IR(N)). The mean output code of EK-IR (N) for Pasture 2 was 131. The estimated yield for Pasture 2 using the above equation is 1744 lbs/A. This compares favorably with the estimated mean yield from the ground observations of 1830 lbs/A.

Extrapolation of these results was explored using interpretive and enhancement techniques. The first of these techniques was manual photo interpretation. Once determined for the test sites, the photographic tones and patterns that correlated with range site and range yield were extended to adjoining areas and subsequently to adjacent photographs. Unfortunately, the consistency of this interpretation was difficult to maintain and was subject to considerable bias.

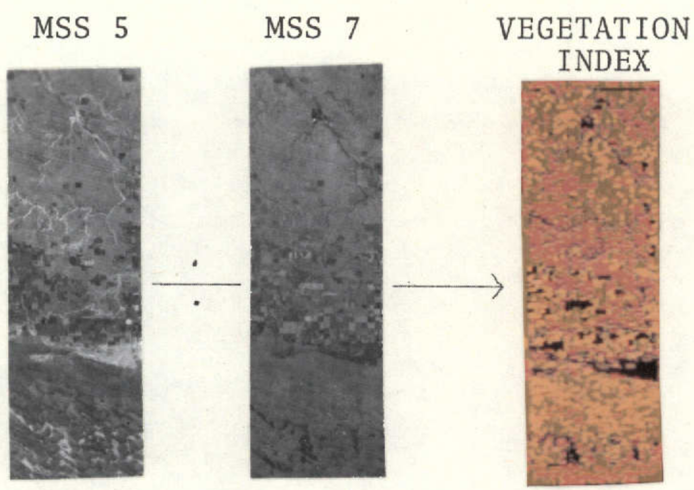
With this in mind, a semiautomatic method was attempted by using density slicing (Figure 6). This density slicing device allowed the interpreter to color-encode the gray tones on a photograph into 32 colors. Once the device was set up and calibrated for a test site, adjacent areas with characteristics similar to the test site were surveyed. For example, the display of Pasture 1 was matched to a two-class range site map. Without adjusting the density slicing device, an adjacent pasture (Pasture 2) was displayed, and the resulting range site map of Pasture 2 was compared to the field data from 49 ground

points. The results showed that 84 percent of the ground points agreed with the extrapolated range site map (Figure 6). A similar test with two forage yield classes showed the extrapolated yield map to be 90 percent correct.

Extrapolation in this manner is also possible using the SADE in the off-line mode except that the SADE can only display 16 colors or gray levels as opposed to 32 levels on the Spatial Data equipment. Of course, extrapolation is also possible when on-line with the computer, although fees for computer usage are incurred. The additional expense may be warranted, however, since the extrapolation results can be stored on computer tape.

Unfortunately, extrapolation using the techniques outlined above was limited to a small portion of the photograph due to the degrading effects of sun angle and vignetting. Because corrections currently in use are so complicated that they are impractical at this stage of technology for use with low-altitude photography, attempts were made to develop a simple empirical correction or solution to the problem. A ratio of the black and white film with the red filter (B/W-25A) and the black and white infrared film (B/W-89B) failed to eliminate the degradation. A subtraction of the overlapping photographs also proved unsuccessful. Even if these corrections had been successful, they may have proved impractical, since the cost of digitizing and correcting a large number of frames of imagery may not be a practical way of extrapolating from test sites.

Due to the problems inherent with low-altitude photography and the nonavailability of high-altitude photography, ERTS-1 imagery was evaluated as a way of extrapolating to large areas. ERTS-1 imagery has several advantages. It is multispectral, provides a synoptic view, and offers the advantage of concurrent coverage several times during the growing season. Imagery from the August 18, 1972, overpass was selected for analysis. Transparencies from MSS 4, MSS 5, MSS 6, and MSS 7 were visually compared. The imagery from MSS 5 and MSS 7 was selected for detailed analysis, since the vegetative differences were more pronounced in these bands. An 8 x 32 mile area encompassing the Bennett County flight line was masked out and digitized with the Signal Analysis and Dissemination Equipment (SADE) for both MSS 5 and MSS 7. The resulting output codes were then subtracted (5-7) and ratioed (5/7). The four sets of data (5, 7, 5-7, and 5/7) were printed out and visually compared with the land use for the area and the results from a radiometric study conducted on August 22, 1973. The ratioed data (5/7) were most sensitive to vegetative differences and demonstrated a strong inverse relationship to forage yield. Comparable results were obtained from measurements of several range sites and field canopies with the Exotech radiometer. A vegetative index was developed with six classes that related to range site and forage yield (Figure 7). Within a general area of similar soils and range sites, this index is a good measurement of vegetative cover.



LEGEND

1	Dark →	SubIrrigated
2		Overflow
3		Silty/Shallow
4		Sandhills/Thin Upland
5		Stubble
6	Light	Fallow

Figure 7. Vegetation index with six classes derived from ratioed ERTS data.

SUMMARY AND CONCLUSIONS

In summary, field data collected during July and August of 1972 were compared to imagery for the same period in an effort to develop a technique for estimating herbage yield and other soil and range properties that would ultimately result in improved and updated soil and range inventories. Field data collected at 100-meter intervals and digitized film data from several test sites were analyzed using statistical and pattern recognition techniques. The results of the analyses were subsequently extrapolated from the test sites to the remainder of the study area using visual and semiautomatic methods.

The variables such as depth of A horizon, percent slope, reflectivity, and herbage yield were significantly correlated with the digitized film data. The correlation coefficients between the variables and the various film variables were not significantly different except for the black and white infrared film, which was not significantly correlated with any of these field variables. Addition of digital data from more than one film variable did not significantly improve the correlation between the field and film data. Transformations of the film data also did not significantly improve the correlation.

Computer classification of yield and range site maps was accomplished using pattern recognition and interpretation techniques. One feature (film variable) was adequate for predicting yield and mapping range sites. The yield equation determined from the test site

was extrapolated to another similar field. The mean yield (lbs of dry matter per acre) of 1830 lbs. was estimated within 86 lbs. The range site classification was extended using density slicing. Eighty-five percent of the ground points in the test field were correctly classified. Extrapolation using these methods may not be feasible for use with photography due to the effects of sun angle and vignetting. Ratioed ERTS-1 data provided a practical but somewhat less precise solution for extrapolation to large areas. A ratio of MSS band 5 to MSS band 7 was inversely related to vegetative cover and yield.

The results obtained from extrapolation were less than desired due to the large variation between yield subsamples and the inability to extract radiometric type data from aerial photography. If ERTS-1 imagery or aircraft photography is to be used to predict range yield or range conditions, it is recommended that the imagery be used for stratification of ground areas before ground sampling is conducted. On this project the field data were assumed to be correct and the film data compared to it. It is hypothesized that better results would have been obtained by stratifying on the film data and comparing field data to film data.

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RECOMMENDATIONS

The use of low-altitude imagery for determining range conditions or yield is severely limited by sun angle and vignetting effects on film density. Until new developments or techniques for correcting these effects are economical, it appears impossible to use low-altitude imagery for anything other than sampling detailed test sites. High-altitude imagery may have been more useful because it covers larger areas. However, at this time good high-altitude imagery is hard to obtain.

The ratioed data from the ERTS-1 imagery looks the most promising. Still, the problem of where to sample in reference to the reflectance patterns on the ERTS-1 imagery is difficult unless vegetative conditions can be related to several ERTS-1 passes. Considering the techniques available and resource restraints, it is recommended this project be discontinued.